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INVENTORY AND MONITORING OF WESTERN BURROWING OWLS (*ATHENE CUNICULARIA HYPUGAEA*) FOR THE COACHELLA VALLEY MSHCP

BY

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INTRODUCTION

Burrowing owls are currently classified as a "species of special concern" by the state of California due to losses in habitat and other anthropogenic impacts which have led to its widespread decline through the western United States (James and Espie 1997). Because they are a ground dwelling species, burrowing owls are threatened by extensive anthropogenic habitat modification including suburban development, annual disking of fallow fields, and vegetation and pest management in agricultural flood control channels. In addition to anthropogenic habitat modification, threats of concern in this area include vehicle collisions, predation from domestic pets and coyotes, and off road vehicle use which can collapse burrows. In the Coachella Valley, this species is uncommon and the trend in its population is unknown. Due to their species of special concern classification and potential to be negatively impacted by anthropogenic land uses, burrowing owls were included as one of 27 focal species covered by the Coachella Valley Multiple Species Conservation Plan (CVMSHCP).

The objectives for burrowing owls within the CVMSHCP are to maintain and ensure conservation of occupied burrows on current conserved lands, minimize harmful effects to the species, and to identify and implement monitoring and management to sustain the population within the plan area (CVMSHCP, 2007). In support of these objectives, UC Riverside's Center for Conservation Biology conducted a study in 2009 designed to gather preliminary information to guide the establishment of long-term monitoring that would inform adaptive management. Prior to this study, 74 known locations were documented within the CVMSHCP area. Of these, 41 burrowing owls were located within the proposed reserve system (CVMSHCP, 2007). Volunteer based surveys conducted by The Institute for Bird Populations during the 1991-1993 years reported at least 9000 breeding pairs in California with the majority located in agricultural areas of the Imperial and Central Valleys. DeSante et al. (USFWS, 2003) believed when comparing these numbers to surveys done in the 1980s that burrowing owls had been extirpated from many regions throughout California including the Coachella Valley. Despite premature predictions of their demise, burrowing owls are found in a variety of habitats within the Coachella Valley including adjacent to suburban and urban development, washes, fallow fields, sand dunes, agricultural drains, and creosote dominated landscapes. This generalist habitat character makes it difficult to use any specific vegetation types to classify suitable habitat; other features such as soil types and the presence of occupiable burrows may better characterize suitable habitat. In addition, due to the potential non-migratory status of the local subspecies (western burrowing owl [*Athene cunicularia hypugaea*]; Korfanta et. al. 2005), year-round habitat requirements should be considered when identifying critical burrowing owl habitat in the Coachella Valley.

The following were the objectives of this study:

1. Task 1: Develop and implement survey methods useful for monitoring burrowing owls to document the distribution and abundance of owls for a single year (2009) across the Plan area. Evaluate the efficacy of the various potential survey methods by comparing method-specific owl detection rates.

2. Task 2: Develop statistical methods for analyzing owl distributions, relative abundance, and habitat relationships. Specifically, using the data resulting from 2009 surveys, develop two complementary types of statistical models: ecological niche models (Rotenberry et al. 2006) and site occupancy models (MacKenzie et al. 2002, 2006). Since a complete survey of the entire valley is not feasible, robust models are necessary to make inferences about potential habitat for burrowing owls and owl demography in un-surveyed areas.

3. Task 3: Develop a reliable protocol for monitoring burrowing owls throughout the Plan area informed by the results from carrying out the previous tasks. Such a protocol would include the collection of data both relevant to the distribution and abundance of owls throughout the Plan area and capable of tracking changes in these demographic parameters through time. Implementation of this protocol should also provide enough data necessary for a statistically robust analysis of distributional patterns, including both natural patterns and responses to management activities. Ideally, the protocol should be applicable to other areas of similar scale, allowing for comparisons of patterns among systems and thus an increase in general knowledge.

After meeting with the California Department of Fish and Game following completion of our contract, on 2/16/10 and again on 3/23/10, we agreed to evaluate the following additional tasks, to the extent possible with existing occurrence data:

4. Task 4: Examine the extent to which owls occupied CVMSHCP conservation areas both during 2009 and historically to evaluate the relevance of these areas for the conservation and management of this species.

5. Task 5: Re-survey sites historically occupied by owls to evaluate the extent to which historical sites remain currently occupied.

Based on those objectives, specific deliverables included:

1. A geodatabase and template for data analyses.

2. A spatially explicit niche model describing the distribution of potential suitable habitat for burrowing owls in the Coachella Valley.

3. A spatially explicit occupancy model based on the distribution and detectability of burrowing owls in the Coachella Valley in 2009.

4. A narrative report of the CCB's 2009 findings including findings specific to CVMSHCP conservation areas and the extent to which historic owl locations were re-surveyed and continued to be occupied by owls.

5. A protocol for future burrowing owl surveys tailored to the Coachella Valley landscape and informed by the results of this study.

METHODS

Field Surveys

We concentrated our efforts on sampling along 42 routes within the 170,295 ha (420,629 ac.) area of the Coachella Valley of Riverside County, California (Fig. 1A). To adequately sample across a diverse landscape, routes were identified with lengths between 0.5 km and 40 km along roadways that included rural, suburban, and urban landscapes as well as irrigation/flood control areas. Our surveys were split into periods of pre-breeding (January – March 2009), breeding season (April – August 2009), and post-breeding (September- December 2009). Three survey methods were evaluated on each of the survey routes: linear, point counts and audio-playback point counts. Each route was surveyed at least three times to ensure the 95 % probability of detection if owls were present, using at least one of the survey methods during the pre-breeding period (Conway and Simon, 2003). During both the breeding season and post-breeding surveys, each route was surveyed three times, with multiple visits per survey method to each route in each season.

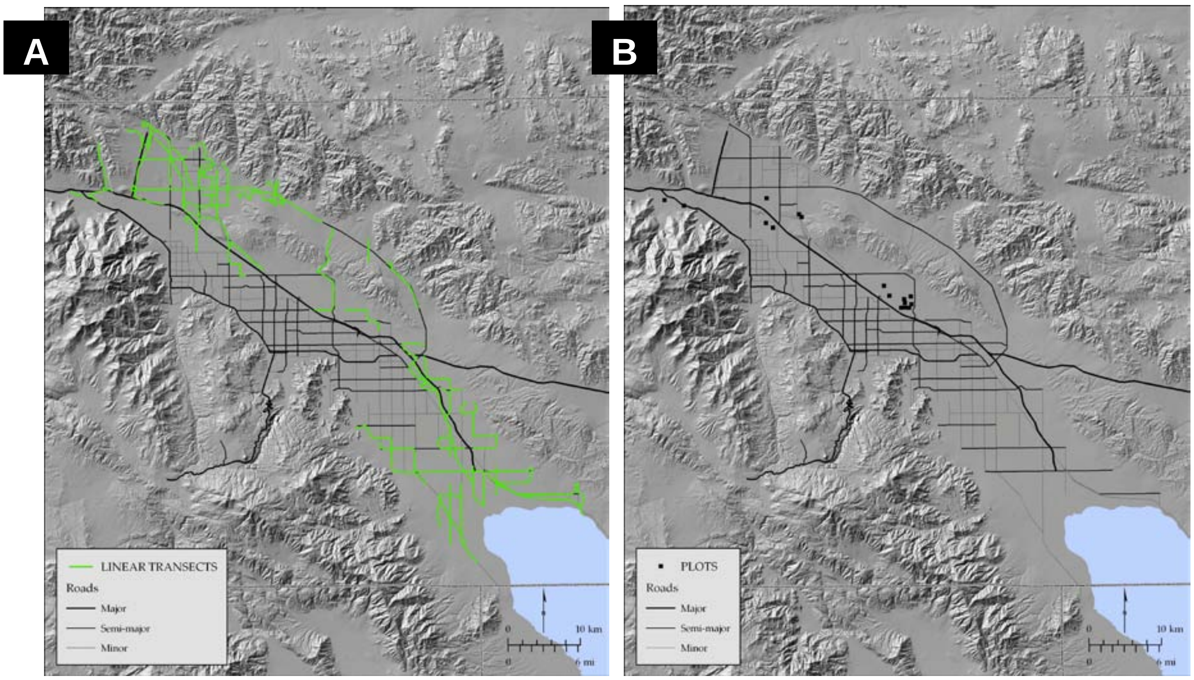

Figure 1. Burrowing owl survey locations implemented by the CCB's in 2009. Green lines indicate survey routes (A), and black squares indicate wildland plot clusters (B).

Linear surveys consisted of driving the routes at a speed below 20 km / hour (15 mi / hr) while scanning roadside habitat continuously, and stopping only when an owl was detected. Visual detections for these surveys were limited to the line of sight from the roadway, and binoculars were only used at locations where owls were observed so as to count the number of individuals at that location. Along certain storm-water drainage routes and riverbeds where driving the route was impossible, surveys were completed on foot. These routes include Mission Creek, Coachella Valley (Whitewater) Storm-water Channel, Buchanan Street Drain, San Gorgonio River, and the Little Morongo Wash. A previous analysis reported that foot surveys were of minimal value as the owls avoided detection at the approach of people (Conway and Simon 2003). However, areas where foot-surveys were conducted were relatively open allowing observers detect owls from a substantial distance, making detection avoidance by owls less of a concern.

Point counts and audio point counts were conducted along these same routes, at 800 m (0.5 mi) intervals. Data were only collected at these established points, where we conducted a four-minute visual search for owls throughout the season. At each stop, the observer would scan the landscape for owls using binoculars for four minutes from the roadside. Audio point counts were conducted in the same manner as regular point counts at these same points, only with a field speaker and iPod that looped Burrowing Owl calls over a four minute playback period. For these, two burrowing owls calls originating from observations at the Salton Sea were downloaded onto an iPOD and broadcast with an amplified field speaker at a volume adjusted to adequately cover a 400 meter radius in all directions from the call. The overall broadcast lasted four minutes and consisted of 12 coo-coo calls (common male call) lasting 30 seconds followed by 30 seconds of silence repeatedly over three minutes. One full minute was then broadcast of the defensive (chuck and chatter) call followed by a full minute of silence for observation.

In addition, to surveys along routes established specifically for this study, we also surveyed for burrowing owls while conducting community-level surveys on *wildland plots* established for monitoring aeolian sand communities (Barrows and Allen 2007). Wildland plots were 106, 10×100-meter plots arranged in 16 plot clusters within the Coachella Valley Preserve. During plot surveys, owls were mainly detected by their tracks, although visual and audio observations were also recorded. Because wildland reserves are largely roadless, on-foot surveys were necessary in these areas. However, our reliance on detecting owls by their distinctive tracks in loose aeolian sand made owl avoidance of surveyors (e.g., Conway and Simon 2003) also of no concern to surveyors employing this method.

To further our general understanding of burrowing owl demography throughout the Coachella Valley, we selected survey routes both within and outside areas conserved under the MSHCP (hereafter *conservation areas*). However, to inform management of MSHCP lands for burrowing owls, we provide additional descriptions of survey results specific to conservation areas. The total length of all survey routes was 445.5 km, of which 32% was within conservation areas. All wildland plots were located within conservation areas.

One additional objective of this study was to re-survey historic owl locations and report the extent to which historic surveys continued to be occupied by owls in 2009. To meet this objective, we first identified detection ranges for our survey methods by examining histograms of distances between owls observed during 2009 surveys and survey site locations. We identified a detection range of 130 meters for linear surveys and 400 meters for point counts and audio point counts. Of the 127 owls detected along survey routes, only five were located outside the detection range of the route or point from which they were detected. We considered the detection range for wildland plots to be 400 meters (the typical size of an owl's home range; Rosenberg and Haley 2004). We examined the extent to which historic locations that fell within the detection range of 2009 surveys were occupied by owls in 2009. We considered a historic location occupied if it was within 400 meters of a 2009 owl sighting.

Database Development

We developed a database in which we recorded fieldwork activity and survey results, and which we designed to support our analyses and this report. The database provides a medium that can incorporate a mix of spatial, temporal, and tabular descriptive information collected during the year. All survey fieldwork locations and owl observation are based on point locations that were manually transcribed from GPS-measured coordinate values. All fieldwork activity and observations include a location, date, and other descriptive attributes. We imported this information into a Microsoft Access relational database management system as tables where domain restrictions could be applied to numeric, temporal, and descriptive attribute values. We used queries to build tabular data subsets based on field methods, observation results, location, and timing of data collection, modeling, and cartographic requirements. All point locations and their attributes were initially converted to shape files and used as reference for creation of linear transect alignments and the plot area locations (still represented as a point). The tabular data and representative geometry were subsequently imported into an ESRI-format file geodatabase. In addition to owl locations from our surveys and survey sites, we also included locations of distinct burrows where owls were sighted, historic owl locations obtained from both 2005-2006 CCB surveys and CVAG's files, and the output of distributional models (i.e., niche models and occupancy models).

Habitat variables

We based niche models and occupancy models on a series of habitat variables compiled using GIS software. These variables were derived from existing GIS layers, calculations from algorithms that convert Digital Elevation Models (DEMs) to topographic metrics, and average annual precipitation (normal precipitation 1971 - 2000 http://prism.oregonstate.edu/docs/meta/ppt_30s_meta.htm, PRISM Group, Oregon State University). Habitat variables considered for modeling were (1) the median terrain slope value for 18 x 18 neighborhood of 10m cells (Slope), (2) mean maximum temperatures in July from 1971-2000 (Max Temperature July), (3) mean minimum January temperatures for the same period (Min Temperatures January), (4) mean annual precipitation from 1971-2000 (Mean Precipitation), (5) median value for 18 x 18 of Sappington analysis results from 3x3 10m neighborhood (Ruggedness 3x3; Sappington et al., 2007), (6) Sappington analysis for 18 x 18 10m neighborhood (Ruggedness 20x20), (7) slope curvature (median terrain curvature value for 18 x 18 neighborhood of 10m cells), (8) average soil water content as fraction of volume, (9, 10) soil composition (percent clay and percent sand), (11) road density, (12) percent agriculture, and (13) percent urban development. Average values for these variables were calculated for 180×180-meter cells for use in niche modeling, and 540×540-meter cells for use in occupancy models. We did not use vegetation type as a potential variable in constructing our models; owls occur across a wide variety of vegetation types (Haug et al. 1993), and thus no single or a few types are likely to be uniquely associated with their distribution in the Coachella Valley.

Niche modeling

We used the Mahalanobis distance statistic (D^2) (Clark et al., 1993; Rotenberry et al., 2002; 2006; Browning et al., 2005) to model the distribution of available suitable habitat for the burrowing owl in the Coachella Valley. The Mahalanobis statistic yields for any location an index of its habitat similarity (HSI) to the multivariate mean of the habitat characteristics at the target species' locations used to generate the model. This statistic has several advantages over other GIS modeling approaches, the foremost being that only species-presence data are required for the dependent variable. Because only positive occurrence data are required, historic location records from museums and field notes can be used, regardless of survey methodology, as long as there is sufficient precision in the site location. This also avoids the uncertain assumption of correct identification of unoccupied habitats (Knick and Rotenberry, 1998; Rotenberry et al., 2002; Browning et al., 2005), an assumption that becomes even more difficult to defend when trying to model historic distributions.

The Mahalanobis statistic may be further refined by partitioning it into separate, additive components (Dunn and Duncan, 2000; Rotenberry et al., 2002; 2006). This partitioning is based on an eigen analysis (principal components) of the variables and observations comprising the calibration dataset. The partition or component with the smallest eigenvalue is associated with the combination of habitat variables that has the least variation among locations, often indicating minimum habitat requirements. This approach is based on the assumption that the full range of habitat variation has been captured in the location data, and that variables that have low variance are more likely to represent limits to a species' distribution than those that take on a wide range of values where a species is present. Identifying the variables that demonstrate the least variability may be more appropriate for modeling potential or historic distributions in changing environments (Dunn and Duncan, 2000; Rotenberry et al., 2002; 2006). We calculated Mahalanobis distances and their partitions with SAS code provided by Rotenberry et al. (2006).

To construct niche models, we used 135 burrowing owl locations including owls recorded during the 2009 surveys for this study, owls recorded incidentally by Center for Conservation Biology (CCB) students and staff during 2003-2008 surveys for other species, and historic burrowing owl locations provided by CVAG. To avoid model over-fitting, we maintained a variables-to-observations ratio of approximately 1:10 (one variable per 9-10 observations). We considered forty independent observations as the minimum threshold for modeling (i.e., allowing a niche model containing up to four habitat variables). The database contained a total of 309 owl locations. However, for each set of observations occurring within a 180×180-meter niche model cell, only one observation was randomly selected to be used for niche model construction; 195 observations were thus selected. By only using these *spatially independent* locations to construct niche models, we avoided over-weighting models in favor of easy-access or high-visitation areas. Sixty of spatially independent locations (30%) were randomly selected and assigned to the *validation dataset*. The remaining 135 observations were assigned to the *calibration dataset* (well above our minimum requirement of 40 observations), which we used to construct niche models.

We evaluated model-performance by examining the extent to which models described locations in the validation dataset as suitable for owls. For each Mahalanobis distance partition, we calculated HSI values for every cell on the map. Following Rotenberry et al., (2006), HSI was rescaled to range from 0-1, with 0 being the most dissimilar and 1 being the most similar to the mean habitat characteristics of the target species based on the calibration data set. We constructed niche models using various combinations of environmental variables, each of which yielded multiple models (i.e., Mahalanobis partitions). We identified the best-performing models as those that assigned the highest median HSI value to locations in the validation dataset.

Occupancy modeling

We developed single-season, single-species occupancy models (MacKenzie et al. 2002, 2006) for calculating spatially explicit probabilities of burrowing owl occurrence across the Coachella Valley. Occupancy models are designed to analyze presence-absence data generated from surveying sites of which some substantial portion are visited more than once where the probability of detecting a species at a site given its presence (*detection probability*) is < 1. Underlying assumptions include a constant occupancy status of individual sites across surveys and no un-modeled heterogeneity in either occupancy or detection probabilities across sites and surveys. An occupancy model contains both a logistic model describing occupancy probabilities and a second logistic model describing detection probabilities, where detection is dependent on a site's occupancy status. As such, models can include covariates that are explicitly related to occupancy, detectability, or both. Multiple models with various combinations of covariates can be fitted to the data and compared under an information-theoretic framework (Burnham and Anderson 2002). From the best-fitted models, one can calculate occupancy rates for both surveyed and non-surveyed sites corrected for imperfect detection and from these infer a species' distribution within the study area.

We fitted occupancy models to the data collected from surveys for burrowing owls conducted in 2009. We modeled occupancy for 540×540km cells, because these approximated the size of an individual owl's home range (0.4 – 0.6 km in radius; Rosenberg and Haley 2004), making occupancy independent among cells. The data consisted of either a 0 (non-detect) or 1 (owl detection) for each day for each cell that was sampled by a survey. Covariates of detection probabilities included (1) the survey method used, (2) survey effort, (3) interactions between method and area (Method × Area), Date (day-of-season of survey), Date + Date^2 (the quadratic transformation of date), and date interactions with two methods (audio point counts [APC] and wildland plot surveys; e.g., APC × Date, Plot × Date). Survey effort was represented as either the area of a given cell within the detection range of the surveyed location (linear survey=130m, point=400m; based on examination of method-specific distributions of distances from survey locations to owl locations) or plot area (i.e., 10×100 meters per wildland survey plot within a cell). We included Date × APC and Date × Plot parameters because we expected different seasonal patterns in detection probabilities associated with these methods (described further in Discussion). We initially considered 12 environmental covariates of occupancy probabilities: elevation, slope, terrain curvature, maximum July temperature, minimum January temperature, average precipitation, Ruggedness 3x3, average soil water content, road density, % aeolian sand, % development, and % agriculture. Additional variables (described previously) were highly correlated with one or more of these variables and therefore not considered. We fitted occupancy models to both breeding data (April-August) and post-breeding data (September-December; pre-breeding [January-March] were sparse), but models fitted post-breeding data poorly probably because owls move around more during the non-breeding season (G. Short pers. com.), which violates the model's assumption. Thus, we only report occupancy models fitted to survey data from the breeding season.

We fitted occupancy models to breeding-season data in R using code adapted from Royle and Dorazio (2008). We initially fitted univariate models to the data. We focused subsequent model construction on detection and occupancy covariates that improved model-fit relative to intercept-only models. We fitted models with various combinations of detection covariates, and we then fitted models with the best combination(s) of detection covariates and all possible combinations of the occupancy covariates that were retained following initial univariate tests. We calculated model weights from AIC_c scores, and we averaged cell-occupancy probabilities across the most heavily-weighted models (Burnham and Anderson 1998). To assess the predictive value of these models, we conducted a goodness-fit-test on the global model ($c = \chi^2_{data} / \chi^2_{boot\text{-}strapped}$; $c > 1$ poor fit and therefore relatively poor predictive value; MacKenzie et al. 2006). We mapped model-averaged occupancy probabilities for 540×540-meter cells using ArcGIS. We only calculated occupancy probabilities for non-surveyed cells that were similar in multivariate, environmental space to the surveyed cells. We assessed the similarity of non-surveyed cells to surveyed cells based on scores generated from a discriminant function analysis (DFA; Tabachnik and Fidell 2001) and HSI scores. In addition to occupancy probabilities, we calculated model-averaged detection probabilities to examine the relative efficacy of the different survey methods for locating owls.

RESULTS

Survey results

In 2009 we recorded 202 sightings of owls at 62 locations (sightings within 400 meters – the approximate diameter of a typical owl's home range – were considered to be in one location) across the Coachella Valley (Figure 2). We recorded 21 sightings in 15 locations during the pre-breeding period, 95 sightings in 35 locations during the breeding season, and 86 sightings in 36 locations during the post-breeding season. In total, 148 sightings were recorded at 41 locations in conservation areas.

In addition to 2009 owl sightings, we compiled 107 "historic" locations of owls including 35 locations recorded by CCB (2005-2006) and the remaining recorded by various observers who contributed to CVAG's records (1985-2001). Seventy-two historic points occurred within conservation areas. We effectively re-surveyed 40 historic sites (33 in conservation areas) in 2009, of which only 13 (12 in conservation areas) continued to be occupied in 2009 (i.e., a 2009 sighting was within 400 meters of the historic location).

Niche Modeling Results

Niche models essentially identified the entire Coachella Valley floor as suitable for burrowing owls (Figure 3). The best performing niche model, based on the highest median HSI value for the validation data (0.99), was comprised of variables that described topography (mainly ruggedness, but also slope and curvature). Those variables described a multivariate mean condition for owl locations consistent with flat terrain. The area mapped as suitable for burrowing owls with HSI values ≥ 0.93 comprised 208,633 ha. Seventy-five percent of both historically and recently observed burrowing owls were located on lands mapped as having HSI values ≥ 0.93. Only 17% of all owls were located on lands of HSI < 0.50.

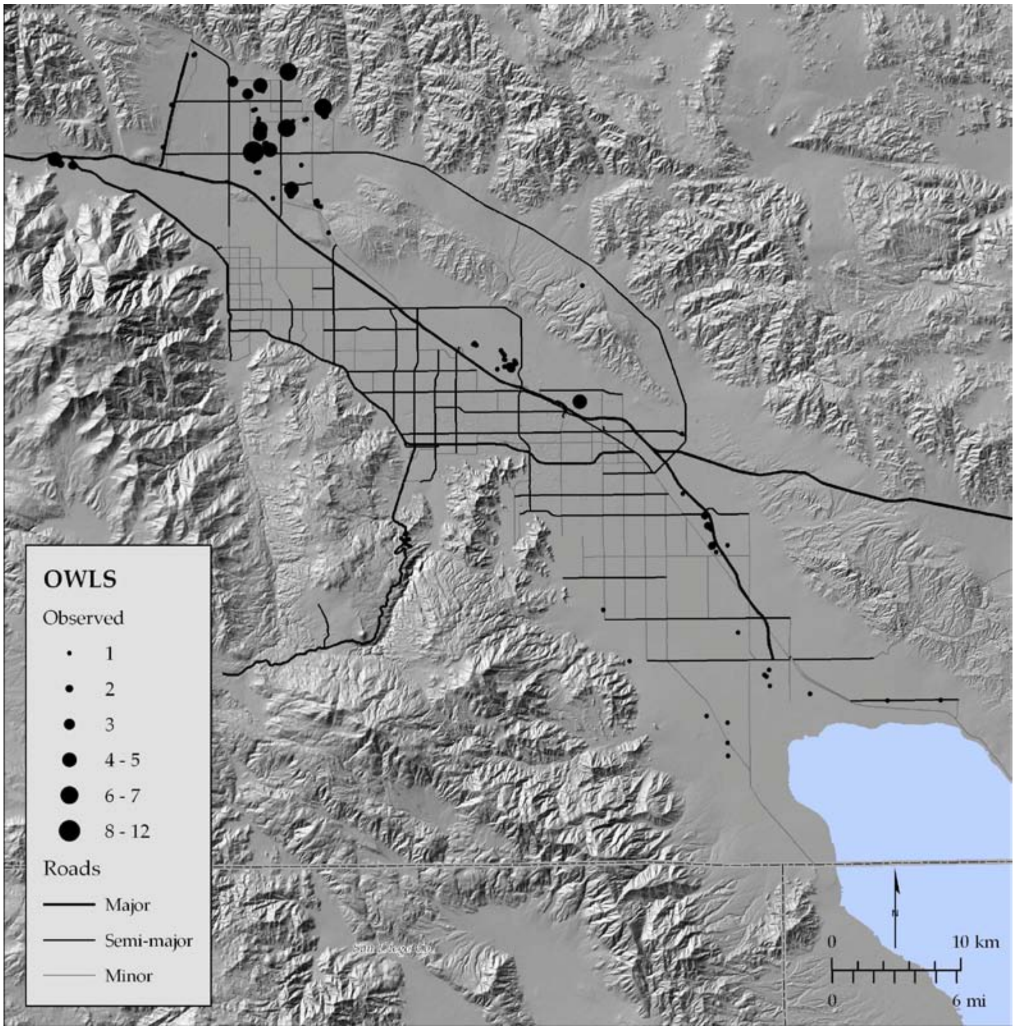

Figure 2. Burrowing owl sightings during 2009 surveys in the Coachella Valley. Dot size corresponds to the number of owls observed during a given sighting.

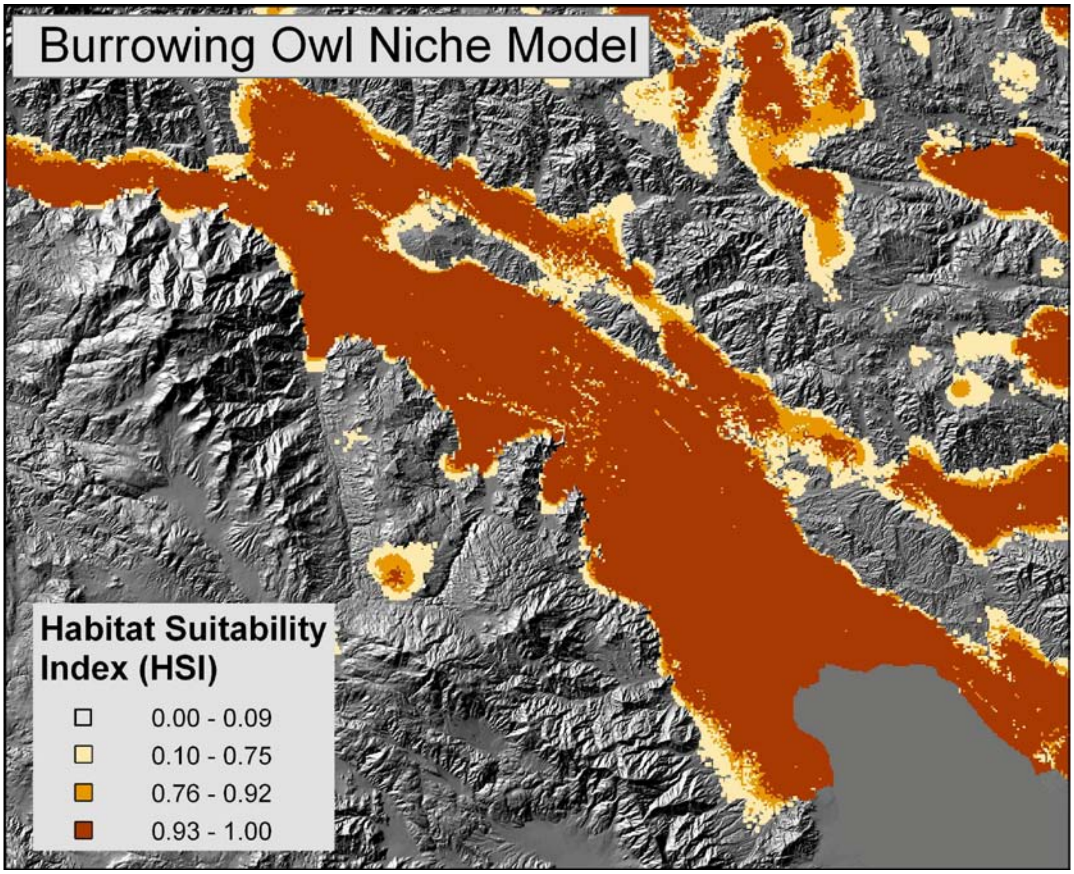

Figure 3. Mapped representation of the best-performing niche model for burrowing owls within the Coachella Valley.

Occupancy model results

Occupancy models identified additional habitat relationships for burrowing owls in 2009. All detection covariates improved model fit during univariate tests. From a set of ten models with various combinations of detection covariates, the top two stood out as the best based on AIC_c-based model weights (*w*). These were a model containing all detection covariates (*w* = 0.79) and a model containing all covariates except the Plot×Date + Plot×Date^2 parameters (*w* = 0.19). Only three occupancy covariates improved model-fit in univariate tests: road density, percent agriculture, and percent aeolian sand. Of a set of 15 models representing all possible combinations of these three occupancy covariates and the two best combinations of detection covariates, the top six models were associated with 95.5% of the statistical weight of evidence. Averaging across these models, cell-specific occupancy probabilities ranged from 0.01-0.43, with relatively high occupancy probabilities associated with foothills and the northern half of the valley floor. These occupancy probabilities reflected strong avoidance by owls of area with a high density of roads, avoidance of agriculture, and a slight affiliation for aeolian sand. We calculated adequate goodness-of-fit (c = 0.59) for the global model (model with all detection and occupancy covariates), so we are confident of the predictive value of these occupancy models.

We found substantial seasonal variation in detection probabilities, as well as differences in seasonal detection patterns among survey methods (Figure 5). The most noteworthy difference in seasonal detection patterns was between linear surveys and audio point counts. Occupancy models identified a dramatic seasonal increase in detection probabilities for linear surveys in contrast with a seasonal decrease for audio point counts. We recorded the most owls during linear surveys, but we attempted relatively few audio point count surveys of owl-occupied cells early in the season when models predicted the highest detection rates (Table 1). In addition, few surveys were made by audio point counts late in the season (August) when detection rates were highest for linear surveys. Furthermore, we recorded a similar ratio of detections/survey-attempts during audio point counts in the month of July as in April, so a U-shaped curve may better describe the actual seasonal detection pattern for audio point counts. Nevertheless, our results strongly suggest that audio point counts yield a higher early-season detection rate than linear surveys. Although model predictions suggest a similar seasonal detection pattern for point counts, we did not include PC×Date detection parameters in our occupancy models. Furthermore, monthly tallies of detections/ survey-attempt ratios for point counts suggested a seasonal pattern similar to audio point counts (i.e., a seasonal decrease). Regardless however, point count detection rates throughout the breeding season were notably lower than either audio point counts or linear surveys (Figure 5, Table 1). Although model predictions for wildland surveys suggested a strong U-shaped seasonal detection pattern (Figure 5), wildland surveys were not conducted early or late in the season (Table 1), so the generality of this pattern is unclear. Nevertheless, detection rates during wildland plot surveys were substantially higher than during any of the other survey methods (Figure 5, Table 1).

DISCUSSION

Our surveys contributed substantially to the available data on burrowing owl distributions within the Coachella Valley. We found 62 independent locations of owls throughout the Coachella Valley, 66% of which were recorded on conservation lands. Although our surveys were distributed across the Coachella Valley, our observations of owls were largely clumped in and around the Desert Hot Springs area (Figure 2). Many of the nest sites found were along Mission Creek, Little Morongo Wash, Hidden Springs (now in development), and other washes, as well as a half dozen nest sites directly adjacent to suburban development. In these areas, nest sites were often observed on the edge of empty development pads, left vacant by the slow in construction during this economic recession. This phenomenon may arise because ground squirrels tend to favor excavating burrows in disturbed soils, resulting in more burrows for

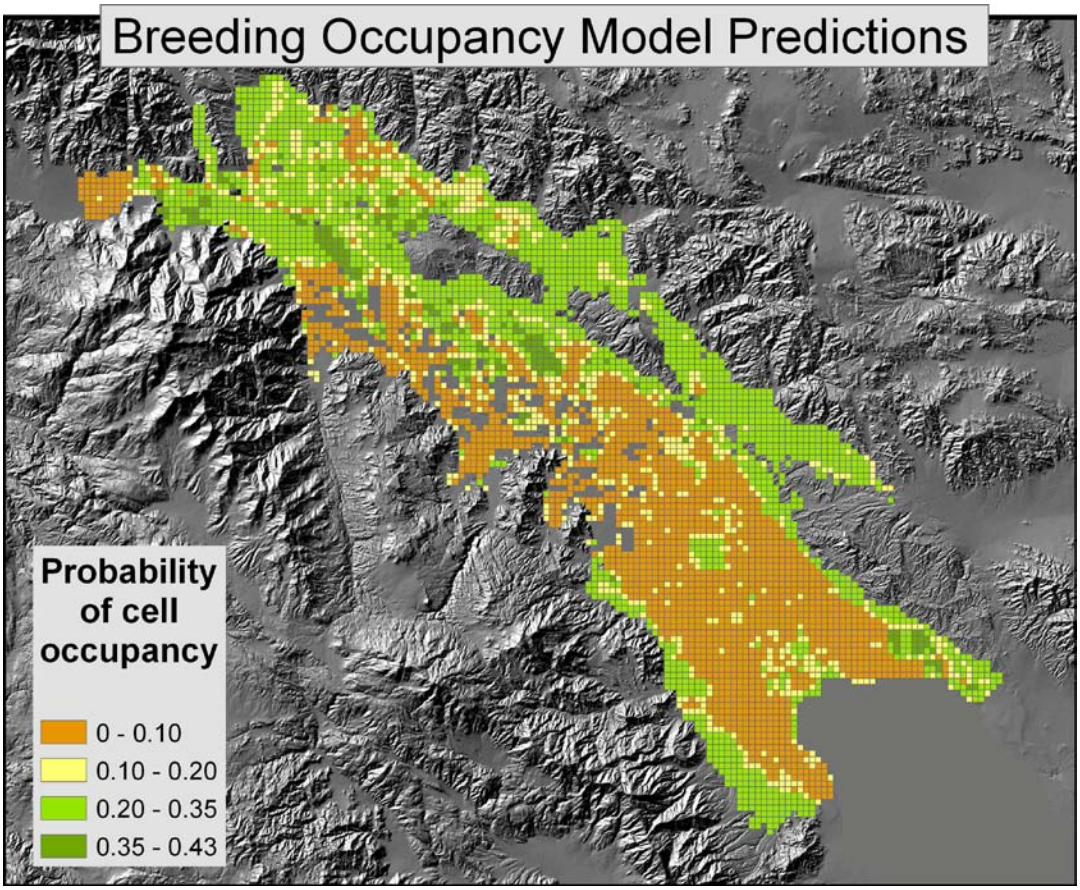

Figure 4. Mapped representation of predicted occupancy probabilities averaged across the best-fit occupancy models fitted to breeding survey data. Occupancy probabilities are not conditional upon survey results, and therefore only reflect habitat relationships calculated from occupancy parameters. Probabilities are depicted on a scale from beige (low probability) to green (high probability). Occupancy probabilities were only calculated for surveyed cells and non-surveyed cells that were similar in environmental space (within 95% CI centered on a multivariate mean generated from a discriminant analysis) and HSI values (>0.21) to the surveyed cells.

owls to use in these disturbed areas. The ability of these owls to take advantage of burrows in high proximity to development makes it imperative that future studies and monitoring efforts catalog potential nests in these areas along roadside surveys or environmental analyses for impact reports. The majority of owls nesting within Mission Creek drainage and Little Morongo Wash are within the areas to be incorporated into the conservation of those corridors. Given their proximity to suburban and urban areas, future study should address the impacts of off-highway vehicle use, dumping, and predation by domestic animals in these areas.

Observations of owls in the southern Coachella Valley were sparser than those found within the Desert Hot Springs area. In the south region, the largest accumulation of nest sites was along the Whitewater (Coachella Valley) Stormwater Channel, which ultimately drains into the Salton

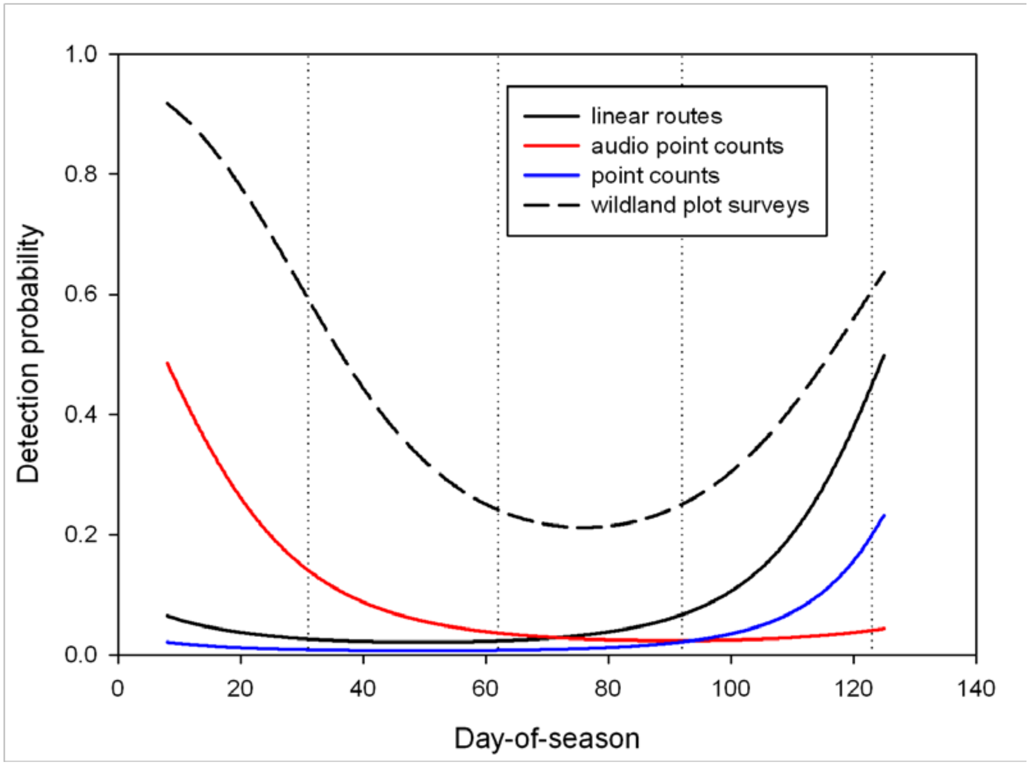

Figure 5. Seasonal progression in model-predicted detection probabilities by survey method. A detection probability is the probability of detecting an owl during a survey when surveying a cell occupied by a burrowing owl. Detection probabilities are for survey intensities (area of cell intersected with the method-specific detection range) averaged across the owl-occupied cell areas surveyed by each of the methods during our study.

Table 1. Number of owl detections / attempts to survey owl-occupied cells by month in 2009.

Month	Linear surveys	Point Counts	Audio Point Counts	Wildland Plots
	# detects / # occupied cells surveyed	# detects / # occupied cells surveyed	# detects / # occupied cells surveyed	# detects / # occupied cells surveyed
April	0 / 8	2 / 3	3 / 7	
May	5 / 19	0 / 20	1 / 2	5 / 16
June	5 / 11	1 / 6	5 / 29	7 / 26
July	4 / 24	1 / 8	3 / 7	12 / 27
early-August	10 / 11			

Sea. The availability of burrows within the Coachella Valley flood control canals, including the Coachella Valley Stormwater Channel, is likely dependent upon land management practices. Large crags in canal banks created from water erosion encourage ground-dwelling rodents to excavate burrows, which in turn become available to burrowing owls. However, canal maintenance activities, such as the use of tractors to flatten crags along canal banks, can destroy burrows and thereby reduce the suitability of these sites for owls. In the Imperial Valley, even though burrow availability was positively correlated with ground dwelling rodents that favor disturbed areas, burrow availability was negatively correlated with the intensity of canal and drain dredging (Rosenburg and Haley 2004). Future canal management activities in the southern Coachella Valley should include collaboration with owl monitoring to minimize destruction of active and/or potential nest sites.

Only a small portion of 2009 owl locations represented continued use of historic locations, suggesting somewhat low site fidelity, which elevates the value of habitat modeling for understanding burrowing owl distributions. Our efforts to model the distribution of burrowing owls should be considered a useful, preliminary step towards understanding this species' range and identifying suitable habitat in the Coachella Valley. The relatively wide range identified by niche models (i.e., the entire valley floor; Figure 3) is probably consistent with the historic distribution of burrowing owls. However, occupancy models suggest that the current range is somewhat more restricted. Occupancy models identified two important habitat relationships with owls: avoidance of roads and avoidance of agriculture. Avoidance of roads may represent an avoidance of extreme urbanization. Although percent development was not of direct importance to owl occupancy, road density was highly correlated with development ($r = 0.73$, $n = 8200$ cells). Compacted soil in heavily urbanized areas that prevent burrow excavation by animals is probably of many factors that prevent owls from colonizing these areas. Although owls avoided agriculture in the Coachella Valley, avoidance of agriculture is not a ubiquitous trait exhibited by this species. Owls in the Imperial Valley thrive in agricultural settings (Rosenburg and Haley 2004). The owls we did observe in Coachella agricultural areas were clustered near "guzzlers" or private aqueducts, so differences in the relationship between agriculture and water could be one reason why owls in neighboring regions seem to exhibit different responses to agriculture.

In spite of their avoidance of roads and agriculture, the generalist aspect of burrowing owl biology was also reflected in our modeled distributions. Even the relatively restricted range suggested by occupancy models predicted a substantial rate of occurrence throughout large parts of the Coachella Valley (Figure 4). However, unlike other generalist species (e.g., American crow, red-tailed hawk), burrowing owls do not appear to occur throughout the range apparently suitable to them. Even the most suitable habitats, models predicted no more than 43% of cells to be occupied (i.e., maximum occupancy probability), with most cell-specific probabilities being < 0.35. Thus, even in areas described as high quality habitat, less than one in three cells large enough to contain an individual home range were predicted to actually contain an owl. Numerous factors could contribute to this apparent lack of habitat saturation. For example, the population could be recovering from past circumstances and is therefore in the process of filling the available habitat. Alternatively, unaccounted-for-factors may be limiting the population, which we think is more likely in this case given the widespread and continued decline of burrowing owls. Fortunately, conservation areas represent much of the undeveloped land apparently most suitable for owls, resulting in high model-predicted occupancy probabilities in conserved areas relative to non-conservation lands. Thus, conservation of lands under the MSHCP is likely to contribute substantially to the continued persistence of burrowing owls in the Coachella Valley.

Occupancy models provided less insight into non-breeding habitat use by burrowing owls. Models fitted post-breeding survey data poorly (boot-strapped c = 1.71), which likely reflects the propensity for owls to move around during the non-breeding season thereby violating occupancy model assumptions. Tracking of marked owls and/or radio telemetry would likely provide better information on non-breeding habitat use. From a cursory examination of mapped owl locations, non-breeding locations were recorded in similar areas as breeding locations, so non-breeding habitat may show some similarities to breeding habitat use.

Survey methods employed in this study represent a promising set of tools upon which to base future owl monitoring. Despite our heavy reliance on roadside surveys to survey owls, we found a negative relationship between road density and the presence of owls. This result suggests that roadside surveys sampled a substantial gradient in road density at the landscape scale, despite being tied to roads. In addition, wildland plot surveys were conducted in relatively roadless areas, so wildland survey data likely provide an important balance to biases present in roadside survey data. Future monitoring efforts based upon roadside surveys should strive to maximize the gradient in road density sampled.

According to detection probabilities calculated from occupancy model parameters, the ideal survey protocol for monitoring burrowing owls in the Coachella Valley would incorporate audio point counts early in the breeding season and linear surveys late in the breeding season, in addition to wildland plot surveys. Our results are consistent with those of Conway et al. (2008), who found increased visual detection of owls with increasing temperature and progression of the nesting cycle (both of which increase with seasonal progression), as well as a decreasing importance of audio detections as the breeding season progressed. Haug and Didiuk (1993) also found that using audio surveys among known nest sites greatly increased detectability, but noted a drastic decline in responses, especially by female burrowing owls, after mid-April. We estimate detection rates of ~0.3 for audio point counts in April on average (i.e., mid-April), and ≥ 0.5 for linear surveys in August. Based on these estimates, the probability of detecting an owl in an occupied site surveyed once with an audio point count in April and once with a linear survey in August would be ≥0.65. With minimal funding for monitoring, we therefore recommend a survey protocol consisting of one audio point count in April (the earlier the better) and one linear survey in August (the later the better) at each site. Funds could be stretched even further by conducting repeat visits to a sub-sample of sites in which owls are likely or known to occur, facilitating detectability estimation, and single visits to the remaining sites. Optimally however, monitoring should incorporate at least two surveys of all sites, and even more surveys at sites where owls are known to occur. Adding linear surveys towards the end of the breeding season would likely result in the greatest improvements to detection rates, but early-season detections could be important for studying other aspects of owl biology (i.e., estimating reproductive success; Conway et al. 2008). Future studies could also incorporate additional survey-specific metrics to improve estimates of detection rates, such as temperature, time-of-day, and progression-of-the-nesting-cycle (Conway et al. 2008).

Future research

Additional research aimed at identifying factors that limit burrowing owls would provide further understanding of the occurrence patterns observed in 2009. Factors not studied here that could affect the presence of burrowing owls include local-scale vegetation structure and the presence of burrowing mammals (e.g., California ground squirrels). In addition, along wildland flood channels, we noticed that many nest sites were at or clumped near roads and bridges. High disturbance of soils in these areas may attract burrowing mammals, or may be related to amount of soil water content attributed to more available runoff next to the road. Thus, even though owls apparently avoid roads at a landscape scale, roads may provide important opportunities for owls to nest at a local scale. The predictive power of occupancy models may be improved by inclusion of model parameters associated with such local-scale factors.

In order to better understand the status and persistence of burrowing owls in the Coachella Valley, and to identify key habitat variables, future research on burrowing owls here should concentrate on:

- Understanding owl movement, site fidelity, how wintering habitat compares to breeding habitat, and juvenile dispersal. Color banding, radio telemetry, or some other method for tracking individuals could be used to answer these questions.
- Attempt to assess breeding success and a minimum number of young produced. The collection and analysis of regurgitated pellets from around the burrow entrance and surrounding perches would inform our management efforts on which prey species such as Palm Springs pocket mouse and various orthoptera are essential to their diets and increase breeding success. York et al. (2002) suggested that burrowing owls' breeding success in agricultural areas of the Imperial Valley was reduced due to the lack of small mammal prey available. If the same is true in the Coachella Valley conservation of wildland owls, where small mammal prey is generally abundant, should be the focus.
- A habitat analysis of the effect of local-scale features, such as vegetative cover density, exotic plant species, and the presence of useable burrows and burrowing mammals. Prevention of owls from occupying burrows surrounded by dense exotic species (i.e., Sahara mustard) is also a topic of concern.
- Creating a niche model for the distribution of California ground squirrels within the Coachella Valley could facilitate the creation of a GIS layer for the squirrels' distribution. That layer could then be incorporated into future iterations of spatially explicit models for burrowing owls.
- Finally, research into the effects of land use and management patterns along flood control channels and in suburban areas might provide land managers with better information on annual timing for vegetation control and dredging within these areas, as well as the effects of rodent management and land use disturbances on this population of burrowing owls.

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